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AN EVALUATION OF VISUAL SEARCH BEHAVIOR ON A CATHODE RAY TUBE UTILIZING THE WINDOW TECHNIQUE

12

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The visual search task in this experiment involved two components: (1) moving or changing of stimuli viewed in the window of a cathode ray tube (CRT) and (2) processing of the stimulus information. In order to view the entire stimulus field, searchers needed to control which section of the super-display they saw in the window. The motion relationship between the entire display and the window is analogous to that involving the principle of the moving part.

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The present study considered whether the super-display should be the static component and the window the moving component or, whether the super-display should be the moving component and the window the static component.

The second aspect of this experiment considered how stimulus information is processed, in relation to the length of a memorized target list. This aspect evaluated two general models of human information processing: serial and parallel.

Ten participants searched a series of alphanumeric displays, presented on a CRT, for specific numeric stimuli (targets). Independent variables were display motion control, length of target list, target density, non-target density, and window size. The effect of time on performance was also measured by blocking trials. Each participant performed at all levels of each variable except display motion. Five participants controlled window motion, and five controlled super-display motion. The basic experimental design consisted of a modified central composite design taken from response surface methodology.

In general, results show that a window technique is feasible and yields satisfactory performance in the context of a visual search task. Data concerning mode of display motion control were mixed. Participants using the moving window found a higher percentage of targets (90.2%) than participants using the moving super-display (82.0%). However, participants in the moving super-display group took less time to view the super-display than the moving window group (161.3 and 177.3 seconds, respectively). There was an interaction effect between target density and trial block. In the first block of trials, target detection performance was relatively constant at all levels of target density. However, in the second and third block of trials detection, performance decreased as target density became greater.

A well-defined target set to be memorized provided evidence favoring parallel information processing rather than serial information processing. Results based on scan rate showed that participants searched the display stimuli as quickly for seven targets as for five or three targets. Information processing tasks of the type in this experiment may evolve from a serial mode into a parallel mode as the target set becomes familiar.

Results concerning the window technique are potentially applicable to any task where the entire display cannot be presented at a time.

Results concerning information processing can help to structure the task in which items to be searched must be kept in memory.

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Tactical Operations & Displays

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FOREWORD

A limited portion of the research effort of the Army Research Institute for the Behavioral and Social Sciences (ARI) is devoted to In-House Laboratory Independent Research (ILIR), Army Project 2T16il01A91B, original research in areas suiting the talents of in-house Army scientists working in problem areas assigned to ARI. Tasks under ILIR include any one of a variety of basic or applied research activities, which may contribute toward problem solving within the ARI mission. For example, the present Technical Paper, completed under the direction of Dr. Edgar M. Johnson, evaluates two aspects of human perception: visual search with a moving window and fixed background versus a fixed window and moving background, and serial versus parallel models of human information processing. Participants searched for specific items on a cathode ray tube (CRT) display in which only a part of the entire display could be scanned at a time.

Results are pertinent to research being done in the Battlefield Information Systems Technical Area of ARI on computerized tactical operations and display technology. In a tactical operations center, a dense information display may be physically impossible to present legibly on a CRT. When this occurs, information could be eliminated from the display or only one part of the entire display could be shown at a time through a window. The present paper indicates the feasibility of the window technique, which the Technical Area will explore and develop.

J. E. UHLANER,
Technical Director

AN EVALUATION OF VISUAL SEARCH BEHAVIOR ON A CATHODE RAY TUBE UTILIZING THE WINDOW TECHNIQUE

BRIEF

Requirement:

To evaluate the feasibility of using a window technique in visual search on a cathode ray tube (CRT). When a dense information display is to be presented on a CRT, presenting all the information at one time is not always possible. One solution is to eliminate some information; an alternative is to present only one section of the total information display at a time.

Procedure:

Ten participants searched a 20-row x 50-column alphanumeric CRT display for designated target numbers. Each person could see only one part of the total display at any time but could control which section of the entire display was presented in the "window".

After mastering the basic techniques in a training session, each participant conducted 30 searches with varying levels of target density and non-target density of the super-display, varying window sizes, and varying lengths of target set, i.e., the set of possible target numbers to remember. Five participants controlled the motion of the window across a stationary super-display and the other five moved the super- display across a stationary window opening. Participants were scored on the percentage of targets detected, time to scan the entire super-display, number of movement errors, and scan rates. Effect of task duration was considered by blocking on trials (trial 1-10, 11-20, or 21-30).

Findings:

The window technique was shown as feasible for searching for target stimuli on a CRT. The participants found most of the targets and made few movement errors. Target density and the display-motion relationship were determined the most important variables. A higher percentage of targets was found by participants using a moving window. However, participants in the moving super-display group made fewer control errors and took less time to view the entire super-display.

Evidence for a parallel model of information processing was obtained by varying the length of the target set. Participants scanned the displays as quickly in searching for seven targets as they did for five or three targets.

Utilization of Findings:

The window technique is applicable to an automated tactical operations center (TOC) situation in which much information must be displayed to a tactical decisionmaker and the TOC staff. For example, it may be possible to retain all the detailed information on a tactical map by displaying only a portion of the entire map at a time. Future research should consider the window technique in conjunction with an additional time-sharing task.

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CHAPTER 1

BACKGROUND

Visual search is a fundamental cognitive process pertinent to many daily activities. Among these activities are searching for a number in a telephone book, looking for a face in a crowd, locating a certain street on a map, hunting for a specific item on a grocery shelf, and scanning the classified ads in the newspaper.

Visual search is also an important aspect of many jobs. Air traffic controllers monitor electronic video displays in order to coordinate aircraft arrivals and departures. Image interpreters search photographic displays for items that might be militarily important. Medical doctors examine x-rays for possible abnormalities.

These examples are but a few of the ways in which visual search is used everyday. In a typical visual search task the searcher proceeds through the total field to be searched in a reasonably consistent pattern.

The searcher may scan row by row, column by column, section by section, or with a more complex pattern. Whichever pattern is used, the searcher processes each stimulus in search of a particular stimulus, i.e., the target, or set of stimuli.

In many instances, the cathode ray tube (CRT) is employed as the visual display device for presenting stimulus material to be searched. CRTs are widely used in airport traffic control centers, libraries, hospitals, etc.

Use of CRTs in visual search tasks, however, is constrained by the physiological characteristics of the human eye which impose minimum resolution requirements on electronic displays. This effectively means that in order to display all stimuli at the minimum resolution level, keeping all stimuli in the same perspective, display stimuli must be magnified.

Very often magnification results in a situation in which the entire stimulus field of interest cannot be displayed on the CRT at any given time. A problem thus arises on how to display visual search fields electronically which cannot be shown as a whole. It has been suggested, e.g., Barmack, 1966*, that large CRTs be developed for such purposes. Such displays do exist today but they are extremely expensive.

*Barmack, J. E., and Sinaiko, H. W. Human Factors Problems in Computer-Generated Graphic Displays. Study S-234, April 1966.

A possible solution to the problem of displaying a visual search field on a CRT which cannot be shown in its entirety is the window technique. The basic idea of this approach is that the viewer sees only a portion of the entire display at one time.

The concept is similar to viewing the countryside through a window of a moving train. The traveler sees only a section of the landscape at any point in time. A similar technique, the moving map display, has been used in the aviation field. (Roscoe, 1967*). However, with the moving map display, as in the case of a traveler on the train, the viewer has no direct control over the area being viewed.

The segment of the moving map displayed to the pilot is a function of the relationship between the aircraft and the earth; the particular section of the countryside viewed by the traveler on the train is a function of where the train is on the rail system.

The idea of using a window display, or similar techniques such as scrolling and paging, on a CRT has been addressed by computer software specialists. (Callan, 1974**; Martin, 1973***). However, no attempt has been made to evaluate these techniques or issues related to the use of this technique in terms of visual search behavior.

This means that no performance data exist which can be used to evaluate the idea; or if warranted, to specify design criteria for a visual search system using the window display technique.

The general purpose of this study is to evaluate the window technique in the context of searching for targets that are embedded in a stimulus field which cannot be viewed in its entirety.

The present situation involves two tasks. One task concerns moving or changing of the stimuli being viewed in the window; the other task concerns processing of the stimulus information. In order for a searcher to view the entire stimulus field, he will find it necessary to control the section of the entire visual field he sees in the window.

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*Roscoe, S. N. The case for the Moving Map Display. Information Display, 1967, 4, 44-46.

**Callan, J. F. Key Decisions in Designing the Picture Systems. Society for Information Display, 1974, 11, 18-23.

***Martin, J. Design of Man-computer dialogues. Englewood Cliffs, N.J.: Prentice-Hall, 1973.

One of the primary issues of this task concerns the motion relationship between the entire display and the window, the principle of the moving part. This study examines the principle of the moving part in regard to the search and task parameters of target density, non-target density, window size and task duration.

The second task in this situation concerns the processing of each stimulus item in order to make a determination as to whether the stimulus is a target or a non-target. Of concern here is how the stimulus information is processed in relation to a memorized target set. This aspect of the study will be used to evaluate two general models of human information processing: serial and parallel.

The Principle of the Moving Part

A window display technique can be used in a visual search task in two separate but not necessarily independent modes of operation. The movement involved could be automatic, moving at a certain rate and in a certain pattern with no control exercised by the user-viewer.

In this case research involving the prediction of search times based on eye fixations as a function of target and non-target stimuli would be particularly pertinent. (Williams, 1966*). On the other hand, the pattern and rate of display movement could be controlled by the user-viewer. The latter situation is addressed in this study.

The decision to permit the user-viewer to control the direction of movement immediately brings about an interesting question. Should the entire display be the static component and the window the moving component? Or, should the window be the static component and the entire display the dynamic component?

To illustrate the operational difference between the two motion relationships, see the upper portion of Figure 1. Assume that the super-display, i.e., the complete area to be searched can be partitioned into a 3 x 3 matrix (Figure 1(a)).

Each cell of the matrix contains stimuli which are not targets and may or may not contain a target stimulus. Assume also that the windowed display can show only one cell at a time and that changing the portion of the super-display in the window means "jumping" from one cell to a completely new adjacent cell.

Now suppose the viewer has searched cell 2,2, Figure 1(b) and wishes to see another cell. If the viewer were to execute a "move right" instruction, what would he then see?

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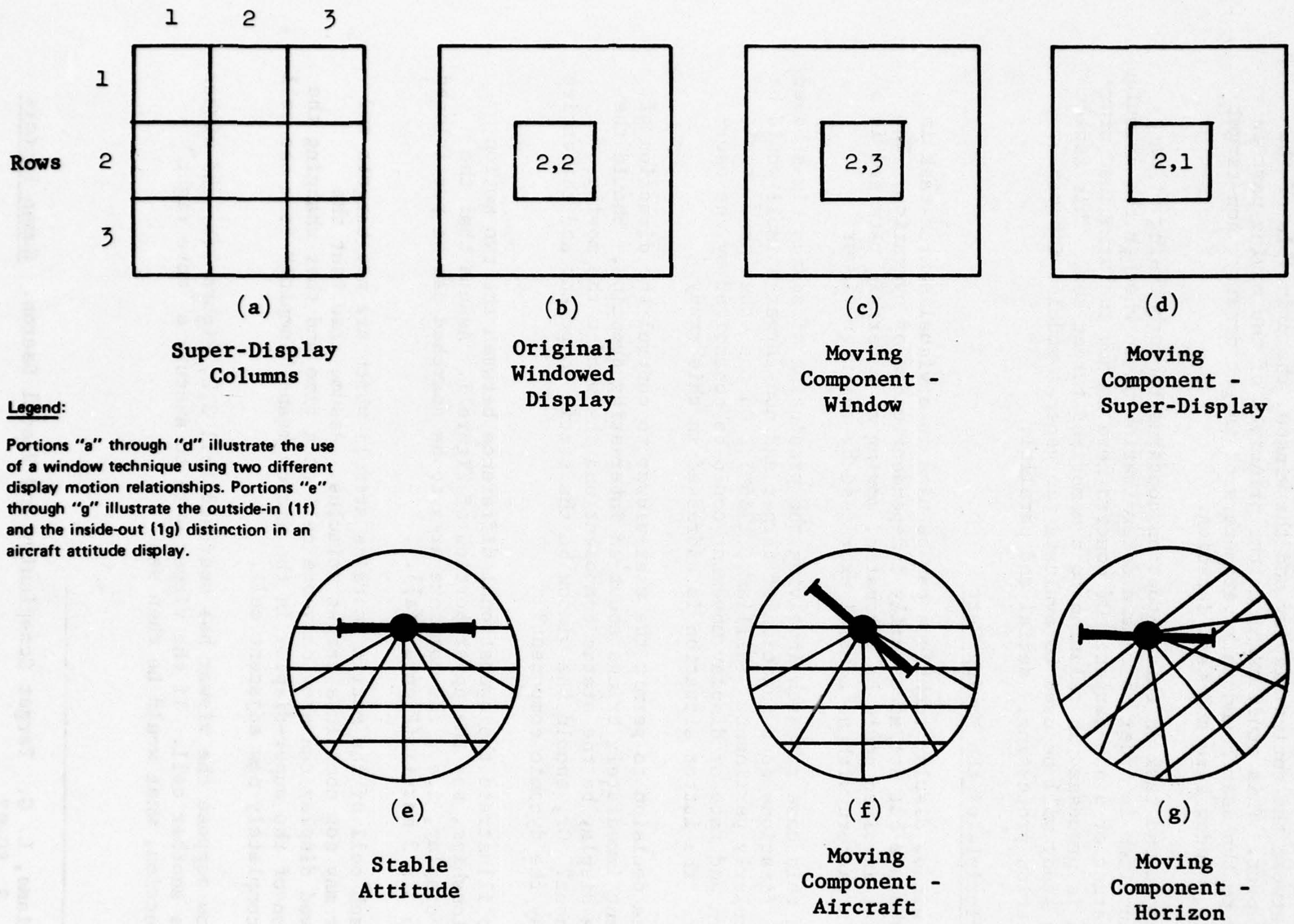
*Williams, L. G. Target Conspicuity and Visual Search. Human Factors 1966, 8, 80-92.



Legend:

Portions "a" through "d" illustrate the use of a window technique using two different display motion relationships. Portions "e" through "g" illustrate the outside-in (1f) and the inside-out (1g) distinction in an aircraft attitude display.

Figure 1. Window Technique Display Motion Relationships.

If the window were the moving element and the super-display the static element, the viewer would see cell 2,3 (Figure 1(c)). If the super-display were the moving component and the window the static component, the viewer would see cell 2,1 (Figure 1(d)).

The lower portion of Figure 1 illustrates that a very similar distinction is made between the inside-out and the outside-in displays in engineering psychology. Assume that the aircraft is flying parallel to the earth (Figure 1(e)) and that the pilot banks the aircraft to the right. What would the display show?

If the aircraft were the moving component and the horizon the static component, the display would look like Figure 1(f). If the horizon were the moving element and the aircraft the static element, the display in Figure 1(g) would result.

Performance differences have been shown between the use of the types of attitude displays just mentioned. Quantitative reports of pilot error indicate that many human errors occur in regard to instrument display reading. (Johnson and Roscoe, 1970*).

One particular type of error, a reversal error, was found in connection with the aircraft attitude display. The typical attitude display studied, still in use today, utilized the aircraft as the static display element and the horizon as the dynamic display element (see Figure 1(g)).

Pilots sometimes were found to misinterpret the attitude display which caused them in turn to make an aircraft control movement which aggravated, rather than ameliorated, the situation. That is, instead of righting the plane from a banked position, the pilot would proceed into a steeper bank.

Two commonly used explanations for this phenomenon involve population or natural stimulus-response stereotypes and the figure-ground relationship. As Chapanis (1972**) and Kelley (1968***) point out, natural relationships should be one of the considerations for designing displays which concern a direction-of-movement relationship.

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*Johnson, S. L. and Roscoe, S. N. What Moves, the Airplane or the World? Savoy, Ill.: Institute of Aviation, Aviation Research Laboratory, Technical Report ONR-70-1, June 1970.

**Chapanis, A. Design of controls. In H. P. Van Cott and R. G. Kinkade (Eds.) Human Engineering Guide to Equipment Design. Washington: Government Printing Office, 1972, 345-380.

***Kelley, C. R. Manual and Automatic Control. New York: John Wiley and Sons, Inc., 1968.

In the situation in which a pilot banks his airplane to the right, it seems natural to expect the aircraft display component to bank to the right. That is, the pilot's control movement and the displayed result correspond.

Since the common practice is to have the horizon tilt or move to the left (the inside-out display), it is easy to see that in periods of stress or disorientation, the pilot may revert to this "natural" mode of responding. This is a common type of error for the situation in which incompatible relationships exist between displays and controls. (Loveless, 1962*).

A second interpretation of the reversal phenomenon involves the figure-ground relationship. (Johnson and Roscoe, 1970, op cit). If the pilot's attention is focused to the outside world he tends to use the earth as the frame of reference, i.e., the ground, against which his aircraft, i.e., the figure, moves. When the pilot shifts his total attention to the inside of the cockpit, it is possible that the figure-ground relationship can change.

That is, the aircraft is viewed as the frame of reference, i.e., the ground, against which the dynamic element, i.e., the figure, of a display moves. If this perceptual reversal occurs the pilot will likely be confused about the relationship between the movement on the display and the display control.

Experimentation involving the inside-out and outside-in displays shows overwhelming evidence in favor of the outside-in display.

Experiments have been referred to by Roscoe (1968**) which show that even those pilots familiar with the conventional inside-out attitude display make fewer errors with the outside-in display. Yet the controversy over which should move, the aircraft or the horizon, is still existent.

As previously mentioned, the display motion question for an aircraft attitude display is not unlike that for a CRT display which utilizes the window display technique. Should the same basic principles hold true in either case? At least one author thinks so.

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*Loveless, N. E. Direction-of-Motion Stereotypes: A Review. Ergonomics, 1962, 5, 357-383.

**Roscoe, S. N. Airborne Displays For Flight and Navigation. Human Factors, 1968, 10, 321-332.

"Although the above principles (i.e., those relating to the designation of the moving component of a display) were crystallized because of their relevance to the problems of aircraft flight and navigation displays, they probably are equally valid for numerous other reasonably corresponding display problems." (McCormick, 1970*).

Assuming that controlling or moving the window is analogous to the outside-in display, performance on a search task should be better in this condition, than in the condition in which the super-display is the moving component. More precisely, the following hypotheses were made:

Hypothesis 1. More targets will be found by those participants using the window as the moving component, as compared to those using the entire display as the moving component.

Hypothesis 2. Less time will be required to search the entire display by participants using the window as the moving component, as compared to those using the entire display as the moving component.

Hypothesis 3. A smaller number of movement errors will be made by the participants using the window as the moving component, as compared to those using the entire display as the moving component.

Above hypotheses are clearly a function of the parameters of the window technique, such as window size, and of the visual search task, such as non-target density, target density and task duration. Parameters are included in this study to examine their relevance for this particular search task and for the hypotheses stated above.

Window size should affect the time to search through the entire display. The smaller the window, the more time is required to manipulate the display controls. Window size also may affect the pattern or algorithm which the searcher uses to view the entire display one section at a time.

For instance, if the window is small, the searcher may not overlap the displays in the window. That is, in changing the window display, the searcher may "move" to a completely new section of the total search field.

However, the searcher may decide to limit the amount of new information he displays, if the window is large. This means that successive displays in the window would overlap in the information presented.

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*McCormick, E. J. Human Factors Engineering. New York: McGraw-Hill, 1970.

Non-target density has been shown related to performance in display oriented tasks. For example, in a target detection task in which stimuli were presented on a CRT, Baker, Morris and Steedman (1960*) found that as the number of non-target stimuli were increased, target accuracy decreased and search time increased. Display studies using different tasks also reveal that increasing display density decreased performance. Baker and Goldstein (1966**) investigated problem solving in two display conditions. In one condition, all possible responses were displayed; in the other condition, responses were displayed which were appropriate at a given point in the problem solving task. Baker and Goldstein concluded that performance was degraded when information with only potential relevance was displayed. In a study on the relative effectiveness of horizontal and vertical displays using alphanumeric stimuli, higher density conditions were found to degrade performance in counting, locating, identifying and comparing tasks. (Coffey, 1961***).

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*Baker, C. A., Morris, D. F., and Steedman, W. C. Target Recognition in Complex Displays. Human Factors 1960, 2, 51-61.

**Baker, J. D., and Goldstein, I. Batch vs. Sequential Displays: Effects on Human Problem Solving. Human Factors, 1966, 8, 225-235.

***Coffey, J. L. A Comparison of Vertical and Horizontal Arrangements of Alpha-numeric Material--Experiment I. Human Factors, 1961, 3, 93-98.

Target density should clearly affect the total time to search for targets. The more targets in the entire display, the longer one should take to search the entire display.

Task duration has been shown to affect performance in a wide variety of situations. Mackworth (1969*) has described a series of studies in which a vigilance effect may not have been attributable solely to temporal uncertainty.

Mackworth wrote that "the vigilance decrement. . . may be particular example of wide-spread phenomenon involving decrease of manual reactivity to continued or repetitive stimulation." In the present situation, the repetitive operational components of the task and the repetitive stimulation of the display may adversely affect search performance over time.

Human Information Processing - Serial Versus Parallel Models

As previously mentioned, the present search task requires the searcher to process each stimulus item in an effort to find the target stimuli. How is the stimulus item on the display compared to the list of known targets in the searcher's memory?

Two general information processing models have been proposed to answer this type of question. A serial model of information processing would predict that each displayed stimulus would be compared individually with each item in the memorized list.

A parallel model of information processing would predict that each displayed stimulus would be compared simultaneously to the entire memorized list.

Serial and parallel models of information processing have actually been developed using two separate but not necessarily independent tasks.

In one task, a designated target is in the array of stimuli. Usually the array of stimuli is presented tachistoscopically and is of variable length. The critical question in this situation revolves around the search time for a target presented early, as opposed to later, in the stimulus array.

A fine background for this literature and its relation to the serial and parallel models is contained in an article by Egeth, Jonides, and Wall. (1972**).

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*Mackworth, J. F. Vigilance and Habituation. Harmondsworth, England: Penguin Books Ltd., 1969.

**Egeth, H., Jonides, J., and Wall, S. Parallel Processing of Multi-Element Displays. Cognitive Psychology, 1972, 3, 674-698.

The other task concerning the serial and parallel processing models typically involves searching a stimulus display for a target that is a member of a variable length target set. The primary question concerning the models in this case is whether or not more time is spent scanning for a target that comes from a long memorized target list as opposed to a short one.

This latter situation is under investigation in this study. An historical perspective on this body of work is given by Neisser (1966) who is also the chief proponent of a parallel model (1963, et al., 1963 and 1964*). His procedure and methodology have become classic in visual search experimentation. Basically the procedure is the following.

The Participant is shown the target memory list, then the stimulus field which is typically 50 rows by 6 columns. The participant scans as in reading, left to right, top to bottom, and then turns a switch when he detects a target. The basic performance measure is time per item scanned.

This is represented by the slope of the best fit regression for data points which show time to find a target as a function of the target position in a stimulus field. This slope is "...unaffected by the time required to begin scanning, to decide upon a response, or to turn the switch." (Neisser, 1963, op cit).

The slope of this regression line, therefore, is a relatively pure measure of time required to process the displayed information.

Using the above procedure and methodology, Neisser showed that 10 different targets could be scanned as quickly as one (Neisser, et al., 1963, op cit). This result was taken as evidence in favor of the parallel model. Neisser's experiment lasted for 27 days and results favoring a parallel model began to appear after several days.

So, if the experiment had been terminated during the first few days, the results could have interpreted in favor of a serial model. Neisser himself indicated that the participants spent the first few days learning the arbitrary set of alphanumerics used as targets, i.e., A, F, K, U, 9, H, M, P, Z, 4.

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*Neisser, U. Cognitive Psychology. New York: Appleton-Century-Crofts, 1966.

Neisser, U. Decision Time Without Reaction Time: Experiments in Visual Scanning. American Journal of Psychology, 1963, 76, 376-385.

Neisser, U. Visual Search. Scientific American, 1964, 210, 94-102.

Neisser, U., Novick, R., and Lazar, R. Searching for Ten Targets Simultaneously. Perceptual Motor Skills, 1963, 17, 955-961.

Other experiments (Kaplan and Carvellas, 1965*; and Cavanagh and Chase, 1971**) have provided evidence for a serial model. In these studies the results were based on a one-day experiment. Sternberg (1966***) also obtained results favoring a serial model in an experiment in which he used a different set of randomized digits in the target set from trial to trial over a short period of time.

In a second experiment, reported in the same 1966 Science article, Sternberg fixed the target set and ran the participants over a much longer period of time, i.e., 60 practice trials and 120 test trials. Results were essentially the same as those obtained in the first experiment.

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*Kaplan, I. T., and Carvellas, T. Scanning For Multiple Targets. Perceptual Motor Skills, 1965, 21, 239-243.

**Cavanaugh, J. R., and Chase, W. G. The Equivalence of Target and Non-Target Processing in Visual Search. Perception and Psychophysics, 1971, 9, 493-495.

***Sternberg, S. High Speed Scanning in Human Memory. Science, 1966, 153, 652-654.

Kristofferson (1972*) tried to duplicate Neisser's results. From data obtained over a long time period, i.e., 25 days, she could not obtain evidence for parallel processing. However, her participants, unlike Neisser's, yielded low error rates. Her conclusion was that highly accurate performance was incompatible with parallel processing performance.

Yonas and Pittenger (1973**) found results similar to Kristofferson (1972).

Egeth, Marcus and Bevan (1972***) obtained interesting results by varying the "naturalness" of the target set. By definition a "natural" target set contained the digits 1, 2 and 3; an "unnatural" target set contained the digits 1, 4 and 7. With the "unnatural" target set, results conformed to a serial model.

That is, scan rate was an increasing monotonic function of the number of targets in the set. But with the "natural" target set, results were obtained conforming to a parallel model. That is, the scan rate was the same regardless of the number of targets in the target set. Also, since the error rate in this study was low, i.e., 1.5%, the scan rate did not agree that a low error rate is incompatible with parallel processing.

Almost all investigators have found that information processing is serial in the early stages of their experiments. The Egeth, Marcus and Bevan study (1972 op cit) which used a well-learned target set was an exception. This study will attempt to replicate the typical finding that the serial model fits the information processing data in the early stages of an information processing task.

In other words, some learning or warm-up is needed to proceed to a more efficient type of information processing, e.g., parallel processing. In regard to the above, the following hypothesis is put forth.

Hypothesis 4. The scan rate will increase as the target memory set becomes larger.

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*Kristofferson, M. N. Types and Frequency of Errors in Visual Search. Perception and Psychophysics, 1972, 11, 325-328.

**Yonas, A., and Pittenger, J. Searching for Many Targets: An Analysis of Speed and Accuracy. Perception and Psychophysics, 1973, 13, 513-516.

***Egeth, H. E., Marcus, N., and Bevan, W. Target-set and response-set interaction: Implications for Models of Human Information Processing. Science, 1972, 176, 1447-1448.

Summary of Hypotheses

The first three hypotheses are specifically related to use of the window technique in the context of the present visual search task. The fourth hypothesis concerns itself with the information processing aspect of the visual search task.

Hypothesis 1. More targets will be found by those participants using the window as the moving component, as compared to those using the entire display as the moving component.

Hypothesis 2. Less time will be required to search the entire display by participants using the window as the moving component, as compared to those using the entire display as the moving component.

Hypothesis 3. A smaller number of movement errors will be made by the participants using the window as the moving component, as compared to those using the entire display as the moving component.

Hypothesis 4. The scan rate will increase as the target memory set becomes larger.

CHAPTER 2

METHOD

Participants

Ten United States Army enlisted personnel who were stationed in the Washington, D.C. area, served as participants. Each participant met both the following criteria: first, 20-20 vision, corrected or uncorrected; second, a score of 100 or higher on the general technical test contained in the Army classification battery. The nine male and one female enlisted participants ranged in age from 18 to 22.

Equipment and Stimulus Presentation

All participants used one of four equally equipped experimental stations (Figure 2). Each booth included a desk with a Control Data Corporation, model 211, alphanumeric CRT. A special function keyboard overlay (Figure 3) specifically designed for this study was used to overlay the standard keyboard. The experimental booth was illuminated with office level lighting. CRT glare and reflection were minimized. A dedicated telephone network was used as a communication device between the participants and the experimenter.

During the experiment, the participants were seated directly in front of the CRT with easy access to the keyboard which was positioned directly below the CRT.

The CRT and the keyboard were linked to a Control Data Corporation computer, model 3300. Control of experimental conditions and on-line monitoring were accomplished by the experimenter via the experimenter CRT. All response data were automatically stored on magnetic disk for analyses.*

In the practice and experimental trials, participants were self-paced in that following the termination of a trial, they could start the next trial whenever they wished.

The stimuli presented on the CRT consisted of the letters D, E, H, K, M, N, P, U, V, W, X, and Y, and the numbers 1, 2, 3, 4, 5, 6, 7, 8, and 9. Stimuli were of two types, targets and non-targets.

The entire set of non-targets was displayed on each trial. Both targets and non-targets were taken from rectangular distributions. The CRT display refreshment rate was 50 frames per second and each "new" window appeared "instantaneously" displayed to the participant.

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*The computer program which presented the experimental stimuli and collected participant data was written by Mr. Charles Marshall, Research Support Group, ARI.

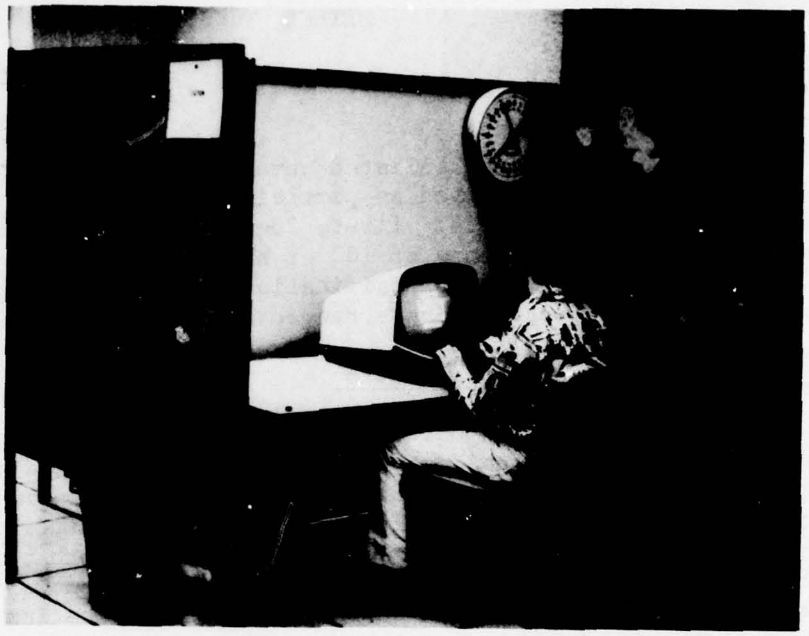

Figure 2. Typical Experimental Station.

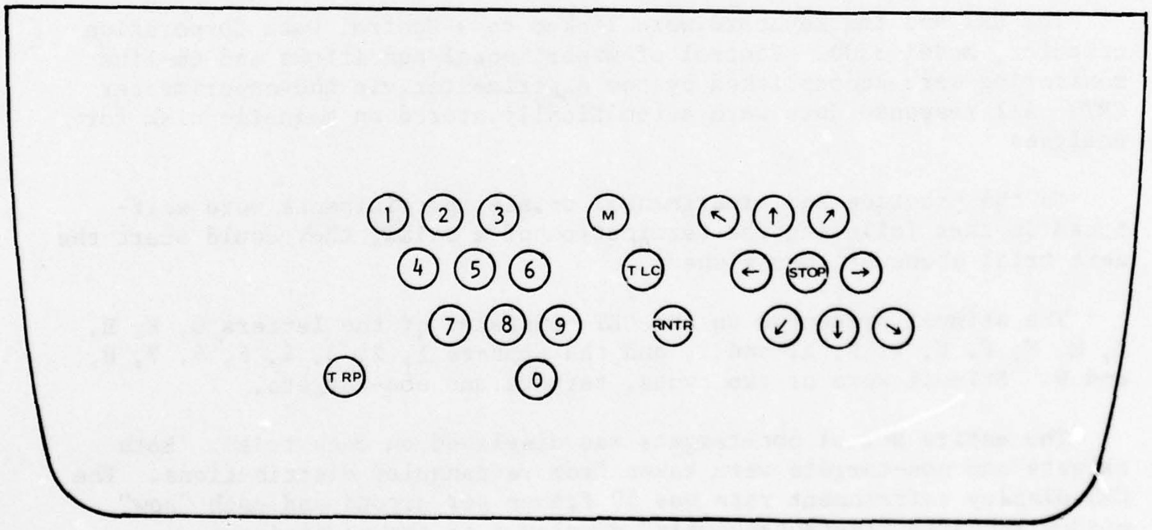

Figure 3. Special Function Keyboard Overlay.

Task

The basic task was to search for a predefined set of consecutive numbers, i.e., the targets, in a field of numbers and/or letters, i.e., the non-targets. The total field searched was a 20 row by 50 column position matrix, i.e., the super-display. This 1000 position matrix was partially filled with targets and non-targets.

A typical super-display is shown in Figure 4. The participants, of course, could not see the super-display in its entirety. Figure 5 shows a typical windowed display, i.e., a part of the super-display seen by the participants.

The experimental task contained two subtasks. First, the participants searched for and reported a target which was always located somewhere in the first portion of the super-display presented. On some trials, more than one target was located in this section.

The upper left-hand corner of this window was always the first row and first column of the super-display. In the second subtask, participants searched the remainder of the super-display for targets using the window technique, since only a portion of the super-display could be seen at one time.

Procedure

Upon the participants' arrival at the laboratory, they were briefed, in general, about the major phases of the experiment. Participants were then randomly assigned to experimental stations. Detailed instructions for the experiment were located in the booth next to the CRT. These instructions are available, on request from the Army Research Institute. A maximum of four participants took part in the experiment at the same time.

The experimental session was divided into two phases, training and performance measurement. The training phase was further separated into two sections corresponding to the two subtasks.

The first section of the training period was devoted to instructing the participant on the procedure used to report a target, to enter the target location, and to scan for targets.

To report a target, the participant had to depress the "T RP" key, i.e., the target report key. He then entered a four digit coordinate indicating the location of the target on the super-display. Lastly, he depressed the "T LC" key, i.e., the target location key, to confirm the location.

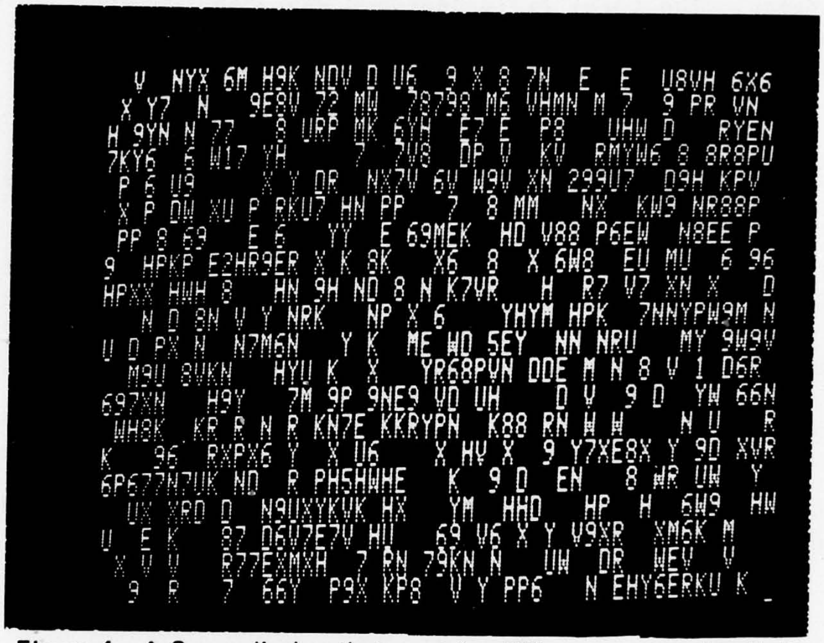

Figure 4. A Super-display that contains 580 non-target stimuli, 7 target stimuli and a target memory length of 5.

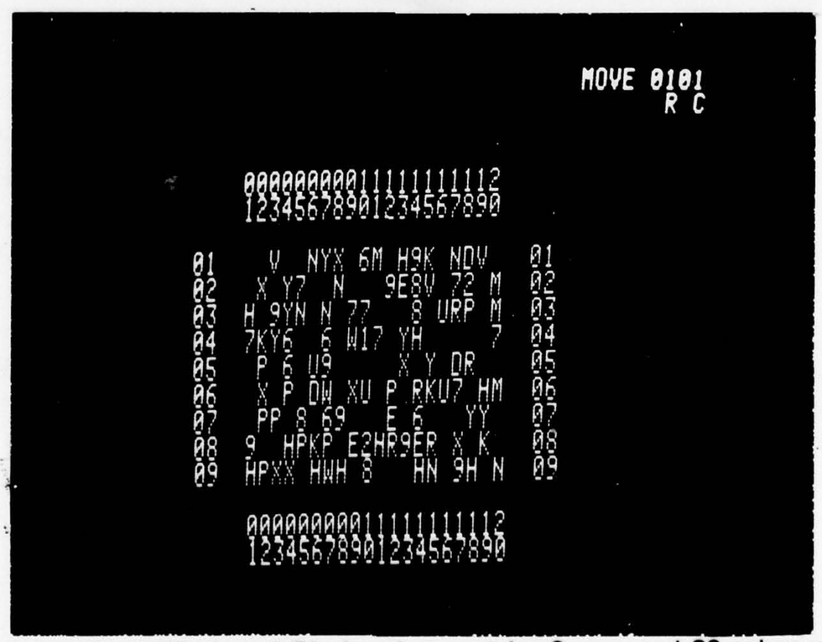

Figure 5. A Windowed Display that contains 9 rows and 20 columns. This display is a portion of the super-display in Figure 4 .

The first section of training also addressed itself to reporting quickly and accurately and locating the first target in each trial. This proceeded as follows. Prior to the start of each trial, i.e., the first view of each new super-display, the participants were shown a five-second target identification message (Figure 6).

The message contained two items of information. First, it identified the numbers which were targets for the upcoming trial. Second, the message displayed a fixation point which indicated exactly where the first row and first column of the super-display would appear on the CRT.

This procedure allowed the participants to start searching for target immediately without having to search for the upper left-hand corner of the windowed display. When the stimuli appeared, the participants were instructed to search quickly from left to right, top to bottom, as in reading. They were told that this was their first task in each new trial.

The first instructional phase was complete for a participant when he achieved a scanning rate, i.e., time per stimulus character scanned, between .03 and .25 seconds for 8 out of 10 consecutive 30-second trials. These scanning rates correspond to lower and upper rates found in the literature.

The scanning rate was determined by dividing the time to find the target by the number of non-targets preceding the target plus one. The time to find the target was the time between the onset of the trial and the depression of the target report key by the participant (see the "T RP" Key in Figure 3).

The scanning rate for the 10 consecutive trials was computed on a moving average basis. A series of 50 such 30-second trials was available for this phase. Between 13 and 44 practice trials were required for the 10 participants.

In the second section of training, the participants were trained to control the display movement. Display movement was controlled by directional command keys, i.e., the arrow keys, and the "M" key which permitted the participant to set the rate of movement (See Figure 3).

The directional keys allowed the participant to control which part of the super-display appeared in the window. To explain how the display movement was controlled, assume that the participant was in the condition in which the super-display was the static component, i.e., the frame of reference, and the window was the dynamic component.

Also, assume the following: the participant completed searching the windowed display in Figure 5; the participant chose to "move" the dynamic component five rows and/or five columns at a "jump" (defined by the contents of the upper right-hand corner of Figure 7); and, the participant wished to view rows 10 through 14, staying in columns 1 through 20 of the super-display.

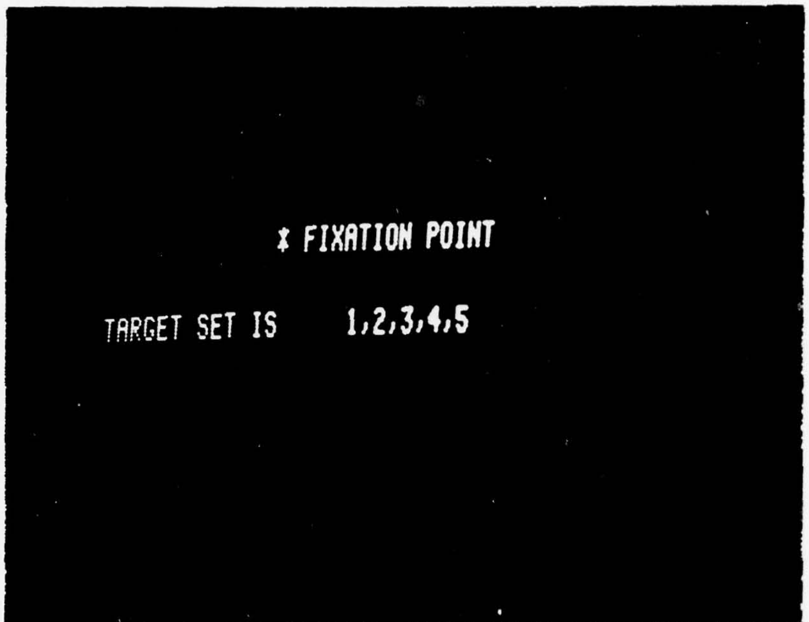

Figure 6. Target Identification Message for a target memory length of 5 and a 9 row by 20 column window.

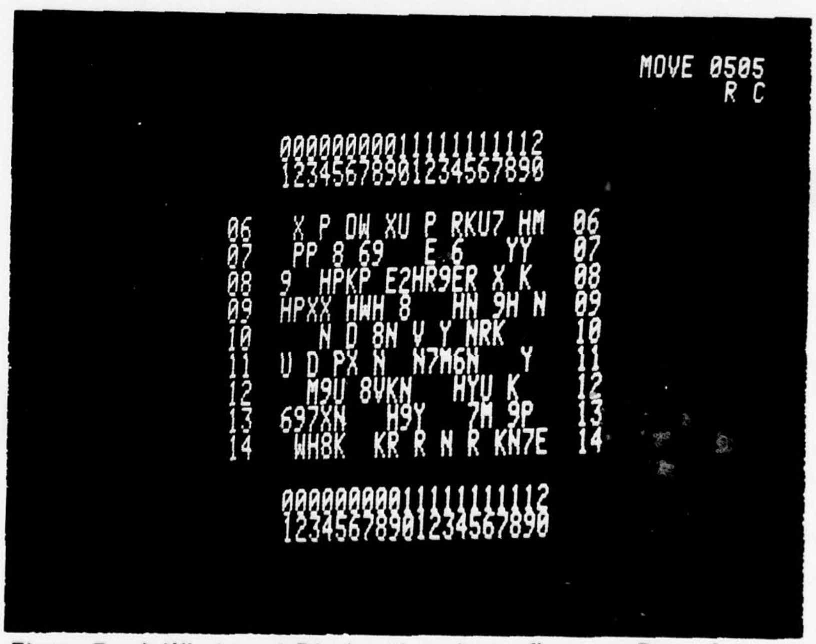

Figure 7. A Windowed Display that shows five new Rows from The Super-Display shown in Figure 4.

To view the desired rows, the participant would have depressed the " ↓ " directional command key and then the "STOP" key. (If the "STOP" key were not depressed, the moving component would continue to move until the 20 row by 50 column super-display boundary was exceeded). The displayed result of depressing the above two keys is shown in Figure 7.

If the participant was in the condition in which the window was the static component and the super-display was the moving component, the directional commands were reversed. For example, the display shown in Figure 7 would result if the participant depressed the " ↑ " key and the "STOP" key.

When a participant told the experimenter that he was familiar with the keyboard and task requirements, he was given a series of four-minute trials.

The second phase of training was completed when the participant was able to bring into view at least 90% of the super-display in 9 out of 10 consecutive trials, computed on a moving average basis. The same series of 50 trials used in the first part of training session was used in this part of the training session.

If the display criteria was not met within the 50 available practice trials, the series was restarted from the beginning. The number of trials needed to meet the display criterion ranged from 17 to 59.

Participants were advised that they were being monitored continually via the experimenter's CRT to insure that they were following instructions during both sections of training. The participants were instructed to call the experimenter on the intercom phone if they had any problems. For a typical participant, the experimenter visited the experimental station four to five times during the practice trials.

When the practice trials were completed, the participants were given 45 minutes for lunch. Upon return from lunch, the participants were given five warmup trials after which the 30 experimental trials were given. The experimental trials were divided into three blocks at 10 trials each. In between blocks of trials, participants were allowed to take a one-to two-minute break in the experimental station. This performance phase of the experiment required 2 1/4 to 3 hours per participant.

The following is a brief summary description of a single trial:

a) The participant initiated the trial by depressing the "T RP" key;

b) The target identification message appeared for five seconds;

c) The upper left-hand corner of a new super-display appeared (this was the beginning of the four-minute trial);

d) The participant searched for the target(s); and,

e) The participant was notified that the four-minute trial was over and the next one was ready to begin.

The first task of the participant in each trial was to find the target in the initial windowed display using the scanning technique learned in the first instructional phase. After finding the first target, the participant was free to search for the remainder of the targets in whatever manner desired.

Independent Variables

There were six independent variables in this experiment.

1. Number of target stimuli in the super-display. The levels were: (a) 1; (b) 4; (c) 7; (d) 10; and (e) 13. The targets were randomly distributed throughout the 20 X 50 super-display.

2. Number of non-target stimuli in the super-display. The levels were: (a) 180; (b) 380; (c) 580; (d) 780; and (e) 980. All rows of the super-display contained an equal number of non-targets in any particular trial. The non-targets were randomly distributed over the super-display.

3. Window size. The levels were: (a) 100; (b) 140; (c) 180; (d) 220; and (e) 260. Each window size was a product of the rows and columns. The window was always 20 columns wide. This corresponded to having windows with 5, 7, 9, 11, and 13 rows.

4. Length of target set, i.e., the set of possible targets for a particular trial. The levels were: (a) 1 (the target was 1); (b) 3 (the targets were 1-3); (c) 5 (the targets were 1-5); (d) 7 (the targets were 1-7); and (e) 9 (the targets were 1-9).

5. Trial blocks. The levels were : (a) trials 1-10; (b) trials 11-20; and, (c) trials 21-30.

6. Display motion. The levels were: (a) the static component was the super-display and the moving component was the window; and (b) the static component was the window and the moving component was the super-display.

Dependent Variables

There were four dependent variables in this study.

1. Percent of the targets detected. That is, the number of targets correctly identified in a trial divided by the total number of possible targets for that trial.

2. Time (in seconds) to display 100% of the super-display on the CRT.

3. Number of directional command errors at the boundary of the super-display. An error was defined as a directional command which requested a display movement which would have resulted in "jumping" farther off the super-display with no new stimuli than had just been presented on the previous windowed display. This dependent variable was intended to be analogous to the pilot reversal error in which the pilot attempts to return his aircraft to its normal attitude, but moves the control so that the aircraft banks to an increased angle.

4. Scan rates (i.e., slope of time to find a target in the first windowed display on each trial, divided by the number of non-targets plus one) for target memory lengths 3, 5, and 7.

Experimental Design

A typical factorial design involving K variables can yield valuable results concerning expected higher-order interactions. If the higher-order interaction terms are thought negligible, however, they are derived needlessly at the expense of time and participants.

Of course, each additional experimental variable increases the number of participants needed by a multiplicative factor. A dilemma thus arises in disciplines such as human factors when a multitude of variables are of concern.

Within the context of a conventional factorial design, a choice must be made between experimental designs which incur high costs associated with the use of many variables, and relatively inexpensive designs which involve only a very few variables at a time.

One solution to this problem involves the use of more economical research designs such as response surface methodology (RSM). "Response surface methodology is a procedure and a philosophy for the design, the conduct, the analysis and the interpretation of experiments performed to determine the quantitative relationship between a dependent variable (the response) and one or more quantitative continuous independent variables" (Simon, 1970*). A particular RSM procedure, the central composite design, was modified for this investigation because of the addition of two variable types not customarily included in the analysis. Before the actual design used is specified, the central composite design is briefly discussed.

*Simon, C. W. The Use of Central-Composite Designs in Human Factors Engineering Experiments. Culver City, Calif: Hughes Aircraft Co., Display Systems and Human Factors Department, Technical Report AFOSR 70-6, December 1970.

The central composite design is based on the assumption that, at most, a second-order regression equation, i.e., a quadratic equation, is sufficient to describe the dependent variable, the response surface, in terms of the independent variables. That is, the researcher believes that a relationship between, let us say, three independent variables can be adequately described by an equation of the type:

$$Y = b_o + b_1 X_1 + b_2 X_2 + b_3 X_3 + b_4 X_1^2 + b_5 X_2^2 + b_6 X_3^2$$

$$+ b_7 X_1 X_2 + b_8 X_1 X_3 + b_9 X_2 X_3.$$

In the above equation b_o is the intercept point and b_1 through b_9 are the coefficients of the corresponding terms in the polynomial. This equation is typically calculated using the <u>least squares technique</u>.

The power of the central composite design resides in the fact that it requires fewer data points than usually associated with a typical factorial.

For instance, as seen above, a 3x3x3 factorial would require 27 data points; whereas a complete three factor central composite design would require only 15 data points to determine a complete second-order equation of the type shown above.

This design is illustrated in Figure 8 (taken from Clark & Williges, 1972*) to allow the reader to see the distribution of data points in in experimental space. The data points consist of 2^3 "factorial points" (2^K) and 2x3+1 additional "star points" (2K+1), including a "center point".

Additional observations at the center point are included in the design to "...help create a uniform information surface... and to ...supply an estimate of experimental error." (Simon, 1970 op cit).

Thus, it is possible to use a relatively few participants to explore and define a K-dimension experimental space using a second-order multiple regression technique.

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*Clark, C., and Williges, R. C. <u>Central-Composite Response Surface Methodology Design and Analyses</u>. Savoy, Ill.: University of Illinois. Institute of Aviation, Aviation Research Laboratory, Technical Report ARL-72-10/AFOSR-72-5, June 1972.

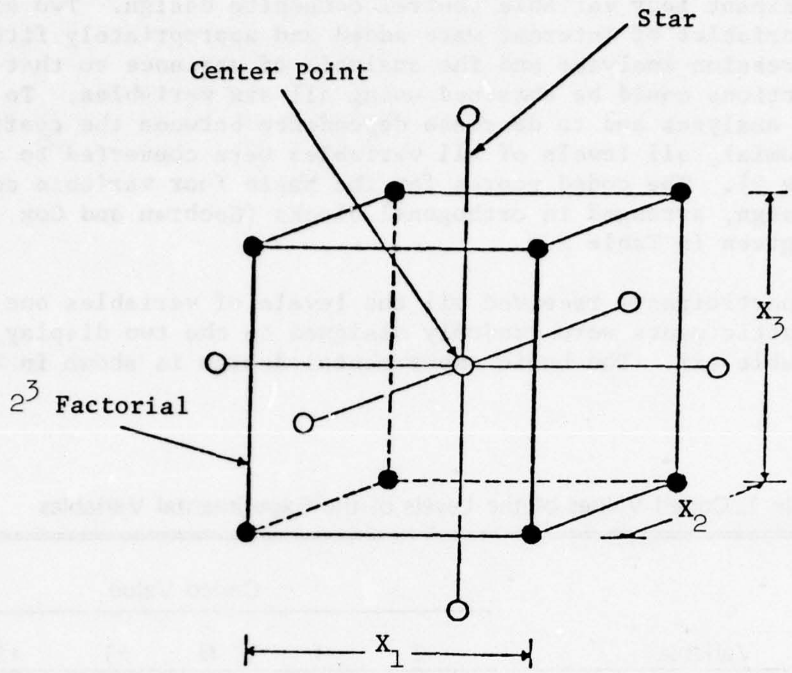

Figure 8. Three-factor, Central-Composite Design.
(From Clark and Williges, 1972, op cit.)

RSM utilizes an analysis of variance on the regression analysis "to test the significance of the given partial regression weights and to test for a significant lack of fit which might indicate additional parameters are necessary in the regression equation." (Clark and Williges, 1973*). The individual weights are tested only to provide an estimate of the relative importance of the independent variables in the response surface. A significant lack of fit means that a regression equation of the third order, or higher, might be needed to fit the data. This can be accomplished by adding more data points thereby using RSM as a sequential experimental design (Cochran and Cox, 1957**; Williges and Simon, 1971***).

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*Clark, C., and Williges, R. C. Response Surface Methodology Central-Composite Design Modifications for Human Performance Research. Human Factors, 1973, 15, 295-310.

**Cochran, W. G., and Cox, G. M. Some Methods for the Study of Response Surfaces. In Experimental Designs. New York: Wiley, 1957, 335-375.

***Williges, R. C., and Simon, C. W. Applying Response Surface Methodology to Problems of Target Acquisition. Human Factors, 1971, 13, 511-519.

The basic design used for the present experiment was a completely-within participant four variable central composite design. Two additional orthogonal variables of interest were added and appropriately fitted into the regression analyses and the analysis of variance so that second-order interactions could be obtained using all six variables. To simplify the analyses and to decrease dependence between the coefficients of the polynomial, all levels of all variables were converted to coded scores (Table 1). The coded scores for the basic four variable central composite design, arranged in orthogonal blocks (Cochran and Cox, 1957, op cit) are given in Table 2.*

All 10 participants received all the levels of variables one through five. The participants were randomly assigned to the two display motion groups, variable six. The basic experimental design is shown in Table 3.

Table 1. Coded Values of the Levels of the Experimental Variables

	Coded Value				
Variable	-2	-1	0	+1	+2
1-Total targets in SD	1	4	7	10	13
2-Total non-targets in SD	180	380	580	780	980
3-Window size	100	140	180	220	260
4-Memory set length	1	3	5	7	9
5-Trial blocks		1-10	11-20	21-30	
6-Display motion groups		WD		SD	

Note. Entries for variable 6 refer to the dynamic component; SD is the super-display and WD is the windowed display.

*The data analysis program for the central composite analysis was programmed by Eloise D. Lyles, Computer Center, ARI.

Table 2. 30 Treatment Conditions.

The conditions are defined by the coded Values of the first four independent variables in three orthogonal blocks.

Blocks											
1				2				3			
X_1	X_2	X_3	X_4	X_1	X_2	X_3	X_4	X_1	X_2	X_3	X_4
1	1	1	1	2	0	0	0	1	1	1	-1
-1	-1	-1	-1	-2	0	0	0	-1	-1	-1	1
1	1	-1	-1	0	2	0	0	1	1	-1	1
-1	-1	1	1	0	-2	0	0	-1	-1	1	-1
1	-1	1	-1	0	0	2	0	1	-1	1	1
-1	1	-1	1	0	0	-2	0	-1	1	-1	-1
1	-1	-1	1	0	0	0	2	1	-1	-1	-1
-1	1	1	-1	0	0	0	-2	-1	1	1	1
0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0

Table 3. Experimental Design

Display Motion Group (Moving Component)	Participants	Trials		
		1......10	11.....20	21.....30
Windowed Display	1 3 5 7 9			
Super-Display	2 4 6 8 10			

CHAPTER 3

RESULTS AND DISCUSSION

The four dependent measures used in this study were:

(1) percent of the targets detected in a trial;

(2) time, in seconds, to display 100% of the super-display on the CRT for each trial;

(3) number of directional command errors at the boundary of the super-display on each trial; and

(4) scan rate, i.e., slope of the time to find the first target on each trial divided by the number of non-targets plus one, in target memory length conditions 3, 5, and 7.

Analyses for the first three dependent variables are based on summary data.

Data were summarized across participants because the primary interest was in describing the dependent variable in terms of the independent variables, i.e., the response surface, and its implications for theoretical issues.

Individual differences were considered irrelevant to this objective and would have complicated the response surface needlessly.

For the first two dependent measures, the raw data were collapsed across participants by using the median value at each treatment, i.e., each combination of variables.

For the third dependent variable, the raw data were collapsed across participants by using the average of the dependent measures at each of the 60 experimental points. The means were used because the median scores for this variable resulted in a distribution with a small range that was severely truncated to the left. This distribution was due to the multitude of zero entries.

The fourth dependent variable was the slope of the scan rate. Due to the nature of the central composite design which provided only one treatment combination at the first or fifth level of the target memory length variable, i.e., conditions 1 and 9, the slope could be computed only for target memory lengths 3, 5, and 7.

The first three dependent variables were analyzed in two ways. First, a second-order regression analysis on the coded scores was computed using the least squares technique.

Second, an analysis of variance was calculated, using the coded scores, to evaluate the significance of the coefficients of the regression equation.

Coded scores were used in both analyses to simplify the analyses. The use of real scores often produces the situation in which coefficients of the regression terms are not independent. With the use of coded scores, all but the coefficients of quadratic terms are independent of one another.

To express the coded relationships in terms of the real values, the following transformation equations were used. The subscripts c and r stand for coded value and real value, respectively:

(1) Target density (TD) $TD_c = \frac{TD_r - 7}{3}$;

(2) Non-target density (ND) $ND_c = \frac{ND_r - 580}{200}$;

(3) Window size (W) $W_c = \frac{W_r - 180}{40}$;

(4) Target memory length (TM) $TM_c = \frac{TM_r - 5}{2}$;

(5) Trial blocks (B) $B_c = \frac{B_r - 2}{1}$;

(6) Display motion (D) -1 = Window moves
1 = Super-display moves.

The analyses of variance for the performance measures of percent targets detected, time to see the whole super-display, and number of directional command errors were based on a general program for analyses involving central composite, response surface designs (Clark, Williges and Carmer, 1971*; and Clark and Williges, 1972 op cit).

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*Clark, C., Williges, R. C., and Carmer, S. G. General Computer Program for Response Surface Methodology Analyses. Savoy, Ill.: University of Illinois, Institute of Aviation, Aviation Research Laboratory, Technical Report ARL-71-8/AFOSR-71-1, May 1971.

Percent of Targets Detected

The second-order multiple regression equation using coded data for the independent variables and median data for percent targets detected are given in Table 4. Beneath the regression equation, the multiple regression (R) and the coefficient of multiple determination (R^2) for the first and second-order regressions are presented.

The second-order equation explains a considerably larger proportion of the variance than the first-order equation (.676 to .348). This additional explained variance is due to the quadratic terms, i.e., the interaction terms and the squared terms.

Note that there is no D^2 term, because there were only two levels of this variable. At least three levels are needed to compute a squared term. This is also true of the remaining second-order regressions.

In the analysis of variance table for percent of targets detected (Table 5), one sees that the second-order regression was significant beyond the .01 level and the lack of fit was not significant. Display motion and target density were significant beyond the .01 probability level.

The display motion group, which used the window as the dynamic component, found a significantly greater percentage of targets than the group that used the super-display as the moving element (90.2% and 82.0%, respectively).

No main effect was associated with blocks. Thus, the replications term was pooled across blocks in this analysis.

The effect of target density was diminished by the fact that the target density and trial block interaction term was significant at the .05 level. Figure 9 illustrates the interaction involving target density and trial block with all other factors constant.

At all levels of target density, in the first block of trials target detection performance was relatively constant. However, in the second and third trial blocks, the percent of targets detected differed greatly depending on the level of target density.

Generally, in the second and third trial blocks, the fewer the targets, the greater the probability that participants would find all targets. Participants often stopped searching with substantial time left in the trial, e.g., 30-60 seconds.

Table 4. Second-Order Multiple Regression Equation

$$
\begin{aligned}
Y_1 = +84.02 \; & -4.31\,TD \; -1.77\,ND \; +1.52\,W \; +1.90\,TM \; +2.48\,B \\
& -4.10\,D \; +0.31\,TD^2 \; +2.37\,ND^2 \; +0.56\,W^2 \; +1.43\,TM^2 \\
& -2.53\,B^2 \; -1.09\,TD \times ND \; -2.34\,TD \times W \; -1.41\,TD \times TM \; -5.16\,TD \times B \\
& +0.10\,TD \times D \; +2.03\,ND \times W \; +1.09\,ND \times TM \; -2.03\,ND \times B \; +0.31\,ND \times D \\
& +0.47\,W \times TM \; -2.66\,W \times B \; -2.15\,W \times D \; -0.47\,TM \times B \; +1.15\,TM \times D \\
& +0.48\,B \times D
\end{aligned}
$$

$$R_1 = .590 \qquad R_2 = .822$$

$$R_1^2 = .348 \qquad R_2^2 = .676$$

Note. Equation for the percent of targets detected which were derived using coded independent values and median dependent scores with multiple R of first and second-order (R_1 and R_2), and with coefficient of multiple determination of first and second-order (R_1^2 and R_2^2).

Table 5. Analysis of Variance Table for the Percent of Targets Detected, Using Median Data

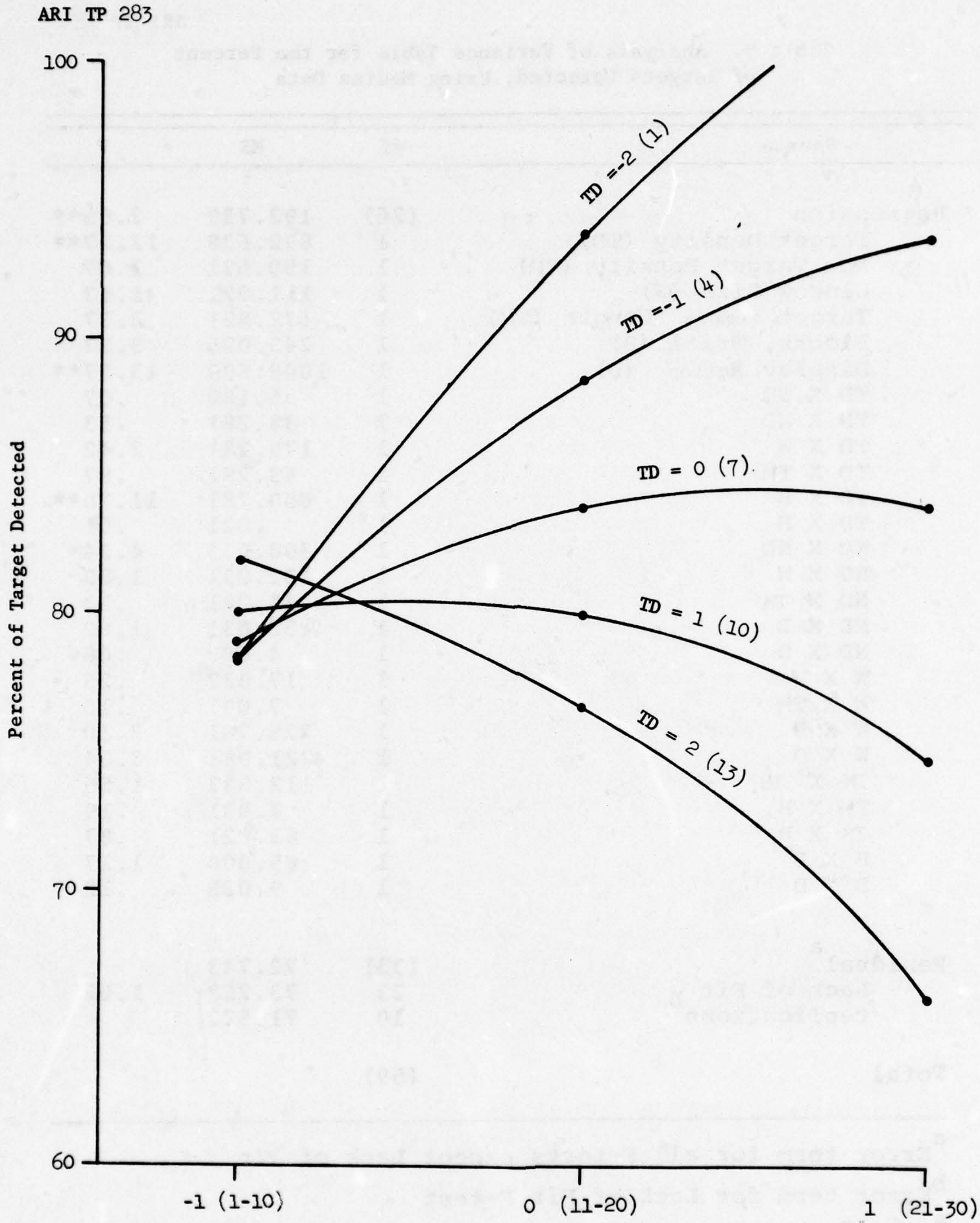
Source	df	MS	F
Regression	(26)	192.739	2.65**
Target Density (TD)	1	892.638	12.27**
Non Target Density (ND)	1	150.521	2.07
Window Size (W)	1	111.021	1.53
Target Memory Length (TM)	1	172.521	2.37
Blocks, Trial (B)	1	245.025	3.37
Display Motion (D)	1	1008.600	13.87**
TD X TD	1	5.180	.07
TD X ND	1	38.281	.53
TD X W	1	175.781	2.42
TD X TM	1	63.281	.87
TD X B	1	850.781	11.70**
TD X D	1	.521	.01
ND X ND	1	308.073	4.24*
ND X W	1	132.031	1.82
ND X TM	1	38.281	.53
ND X B	1	132.031	1.82
ND X D	1	4.688	.06
W X W	1	17.037	.23
W X TM	1	7.031	.10
W X B	1	225.781	3.10
W X D	1	221.081	3.04
TM X TM	1	112.537	1.55
TM X B	1	7.031	.10
TM X D	1	63.021	.87
B X B	1	85.008	1.17
B X D	1	9.025	.12
Residual[a]	(33)	72.743	
Lack of Fit	23	73.252	1.02
Replications[b]	10	71.572	
Total	(59)		

[a] Error term for all F-tests except Lack of Fit

[b] Error term for Lack of Fit F-test

*$p < .05$

**$p < .01$



Interaction effect of target density and trial blocks as measured by percent of targets detected. TD is an abbreviation for target density. The numbers to the left of the parentheses are the coded values and the numbers inside the parentheses are the real values.

Figure 9. Trial Blocks

Usually, this occurred only after the participant displayed almost all of the super-display and at least a few targets had been reported. Participants apparently considered the search task essentially completed after they had seen most of the super-display and reported several targets.

Table 5 shows that the squared term for non-target density was significant. This indicates that detection performance was better for the upper and lower levels of the non-target density levels than for the middle range. It is easy to see why participants detected more targets when non-target density was low; it is not readily apparent why more targets should be detected where the non-target density was high. Perhaps, participants scanned all stimuli more carefully when the display contained more stimuli.

In Table 5 the number of Fs less than one is greater than is found in a typical analysis of variance. The basis for this is that all but one of the F tests are composed of a numerator with one degree of freedom. This results in an F test that is conservative. In fact, Simon (1970 op cit) has stated that with few degrees of freedom, a conservative alpha level, e.g., 0.10 may be adopted.

Time to Display 100% of the Super-Display

The second-order multiple regression equation for time to display 100% of the super-display is shown in Table 6. As with target detections, considerably more variance was explained by the second-order equation (.799) than by the first-order equation (.629).

In the analysis of variance table (Table 7), the second-order regression is seen as significant, whereas the lack of fit and the blocking terms were not significant.

Similar results were obtained for the percent of targets detected. Significant main effects were obtained for target density, non-target density, window size and display motion.

The significance of target density appears due to the fact that in general the more targets there were in the display, the more were reported. And, the more targets that were reported the more time was taken in reporting the detections and locations.

For non-target density, the time to display 100% of the super-display was greater for those in the conditions in which more non-target stimuli were displayed. This simply indicates that participants took more time to process a greater number of non-targets.

Table 6. Second-Order Multiple Regression Equation

Y_2 = 185.37	+26.40 TD	+12.81 ND	-7.48 W	+0.65 TM	+2.50 B
	-8.02 D	-2.82 TD^2	+1.00 ND^2	+0.80 W^2	-9.63 TM^2
	-11.30 B^2	+2.41 TD X ND	-2.97 TD X W	-2.09 TD X TM	+1.66 TD X B
	+1.56 TD X D	+2.34 ND X W	-5.78 ND X TM	-1.28 ND X B	-5.02 ND X D
	+1.47 W X TM	+3.22 W X B	+4.77 W X D	-1.03 TM X B	+0.48 TM X D
	+3.70 B X D				

R_1 = .793 R_2 = .894

R_1^2 = .629 R_2^2 = .799

Note. Equation for Time in seconds to Display 100% of The Super-Display Derived using Coded Independent Values and Median Dependent Scores, With Multiple R of First and Second-Order (R_1 and R_2), and With Coefficient of Multiple Determination of First and Second-Order (R_1^2 and R_2^2).

Table 7. Analysis of Variance Table for the Time (In Seconds) To Display 100% of the Super-Display, Using Median Data

Source	df	MS	F
Regression	(26)	2348.70	5.03**
Target Density (TD)	1	33443.52	71.63**
Non Target Density (ND)	1	7879.69	16.88**
Window Size (W)	1	2685.02	5.75*
Target Memory Length (TM)	1	20.02	.04
Blocks, Trial (B)	1	250.00	.54
Display Motion (D)	1	3856.02	8.26**
TD X TD	1	435.54	.93
TD X ND	1	185.28	.40
TD X W	1	282.03	.60
TD X TM	1	140.28	.30
TD X B	1	87.78	.19
TD X D	1	117.19	.25
ND X ND	1	54.29	.12
ND X W	1	175.78	.38
ND X TM	1	1069.53	2.29
ND X B	1	52.53	.11
ND X D	1	1210.02	2.59
W X W	1	35.75	.08
W X TM	1	69.03	.15
W X B	1	331.53	.71
W X D	1	1092.52	2.34
TM X TM	1	5087.50	10.90**
TM X B	1	34.03	.07
TM X D	1	11.02	.02
B X B	1	1702.53	3.65
B X D	1	547.60	1.17
Residual[a]	(33)	466.87	
Lack of Fit	23	572.76	2.56
Replications[b]	10	223.33	
Total	(59)		

[a]Error term for all F-tests except Lack of Fit

[b]Error term for Lack of Fit F-test

*$p < .05$

**$p < .01$

For the independent variable of window size, the smaller the window size the more time it took to display 100% of the super-display. This was expected since the smaller the window, the more operations the participant must perform on the input keyboard.

As for the display motion factor, the group which used the window as the moving component took more time to display 100% of the super-display than the group which used the super-display as the moving component; 177.3 seconds and 161.3 seconds, respectively.

The squared term for target memory length was significant at the .01 level (Table 7). The participants took more time to see 100% of the super-display when the target memory length was in the middle levels as compared to the extreme levels.

Number of Directional Command Errors at the Super-Display Boundary

This variable is indicative of the relative number of reversal errors that occur in searching the super-display. It was not possible to determine reversal errors when the participant was not on a super-display boundary. The condition existed because it would be difficult to determine whether the participant made a reversal error, or was just interested in seeing a particular portion of the super-display.

If a participant was on a super-display boundary, however, it could be readily assumed that he did not want to move farther off the super-display.

Table 8 provides the second-order regression equation for the number of directional command errors at the super-display boundary. Again, as with detections and display time, the second-order regression explained more of the variance than the first-order regression (.670 to .323). The analysis of variance for the directional command errors is shown in Table 9.

As in the previous analyses the regression was significant, and the lack of fit and the blocking terms were not significant. There were significant main effects for target density, non-density, and display motion.

For target density, the less targets there were, the more directional command errors were made by the participants. This may indicate that the participants concentrated more on finding targets than on moving the display when they didn't have many targets to report.

For non-target density, the participants made more directional command errors with fewer non-target stimuli. Perhaps the more open area in such a CRT display, the more likely that confusion may result due to the lack of stimulus background.

Table 8. Second-Order Multiple Regression Equation for Number of Directional Command Errors At The Super-Display Boundary

$Y_3 = 0.497$	$-.150$ TD	$-.150$ ND	$-.067$ W	$-.025$ TM	$-.113$ B
	$-.155$ D	$+.004$ TD^2	$-.046$ ND^2	$-.096$ W^2	$+.067$ TM^2
	$+.143$ B^2	$+.100$ TD X ND	$+.125$ TD X W	$+.025$ TD X TM	$+.063$ TD X B
	$+.067$ TD X D	$+.050$ ND X W	$+.075$ ND X TM	$+.113$ ND X B	$+.067$ ND X D
	$+.100$ W X TM	$+.013$ W X B	$+.100$ W X D	$+.063$ TM X B	$+.058$ TM X D
	$-.098$ B X D				

$R_1 = .568$ $\quad R_2 = .824$

$R_1^2 = .323$ $\quad R_2^2 = .679$

Note. Equation Derived Using Coded Independent Values and Averaged Dependent Scores, With Multiple R of First- and Second-Order (R_1 and R_2), and with Coefficient of Multiple Determination of First- and Second-Order (R_1^2 and R_2^2).

Table 9. Analysis of Variance Table for Number of Directional Command Errors.

Source	df	MS	F
Regression	(26)	.351	2.70**
Target Density (TD)	1	1.080	8.24**
Non Target Density (ND)	1	1.080	8.24**
Window Size (W)	1	.213	1.63
Target Memory Length (TM)	1	.030	.23
Blocks, Trial (B)	1	.506	3.86
Display Motion (D)	1	1.440	10.99**
TD X TD	1	.001	.01
TD X ND	1	.320	2.44
TD X W	1	.500	3.82
TD X TM	1	.020	.15
TD X B	1	.125	.95
TD X D	1	.213	1.59
ND X ND	1	.115	.88
ND X W	1	.080	.61
ND X TM	1	.180	1.37
ND X B	1	.405	3.09
ND X D	1	.213	1.63
W X W	1	.504	3.85
W X TM	1	.320	2.44
W X B	1	.005	.04
W X D	1	.480	3.66
TM X TM	1	.244	1.86
TM X B	1	.125	.95
TM X D	1	.163	1.24
B X B	1	.271	2.07
B X D	1	.380	2.90
Residual[a]	(33)	.131	
Lack of Fit	23	.102	.52
Replications[b]	10	.197	
Total	(59)		

[a]Error term for all F-tests except Lack of Fit

[b]Error term for Lack of Fit F-test

*$p < .05$

**$p < .01$

Note: The analysis uses averaged data for errors at the Super-Display boundary

Significantly more directional command errors were made by the motion display group which used the window as the dynamic component, 0.69, as compared to the group which used the super-display as the dynamic element, 0.38.

Participant Variability

Summary data (medians and means) procedures were utilized because individual differences, while anticipated, were not considered as paramount to the issues involved. However, separate analyses were conducted to determine the extent of these differences.

For percentage of targets detected, time to display 100% of the super-display, and numbers of directional command errors, the proportion of variance accounted for by participants was .195, .259, and .210.

This high inter-participant variability was probably due to the fact that the small number of participants were selected on the basis of two very general criteria (see Participants, Chapter 2).

Scan Rate

The analysis of variance (Hays, 1973*) of scan rate, i.e., slope , in the target memory length conditions 3, 5, and 7 can be seen in Table 10. Target memory length was not significant. No consistent pattern emerged for scan rate as a result of the considerable variability between participants.

To illustrate the variability, the scan rates for each of the 10 participants at each of the three target memory length levels are graphically presented in Figure 10.

Super-Display Search Patterns

Data were also obtained concerning the search patterns employed by the participants in searching the entire super-display. Basically, the participants "jumped" to non-over-lapping displays. That is, they changed the "M" command to the size of the display.

Then, they changed the display by depressing a directional command key, and after one "jump", immediately depressed "STOP" key. By using this algorithm, it was possible to search the entire super-display without displaying the same stimuli twice. A typical pattern of "jumps" is shown in Figure 11.

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*Hays, W. L. Statistics for the Social Sciences. New York: Holt, Rinehart and Winston, 1973, pp. 568-574.

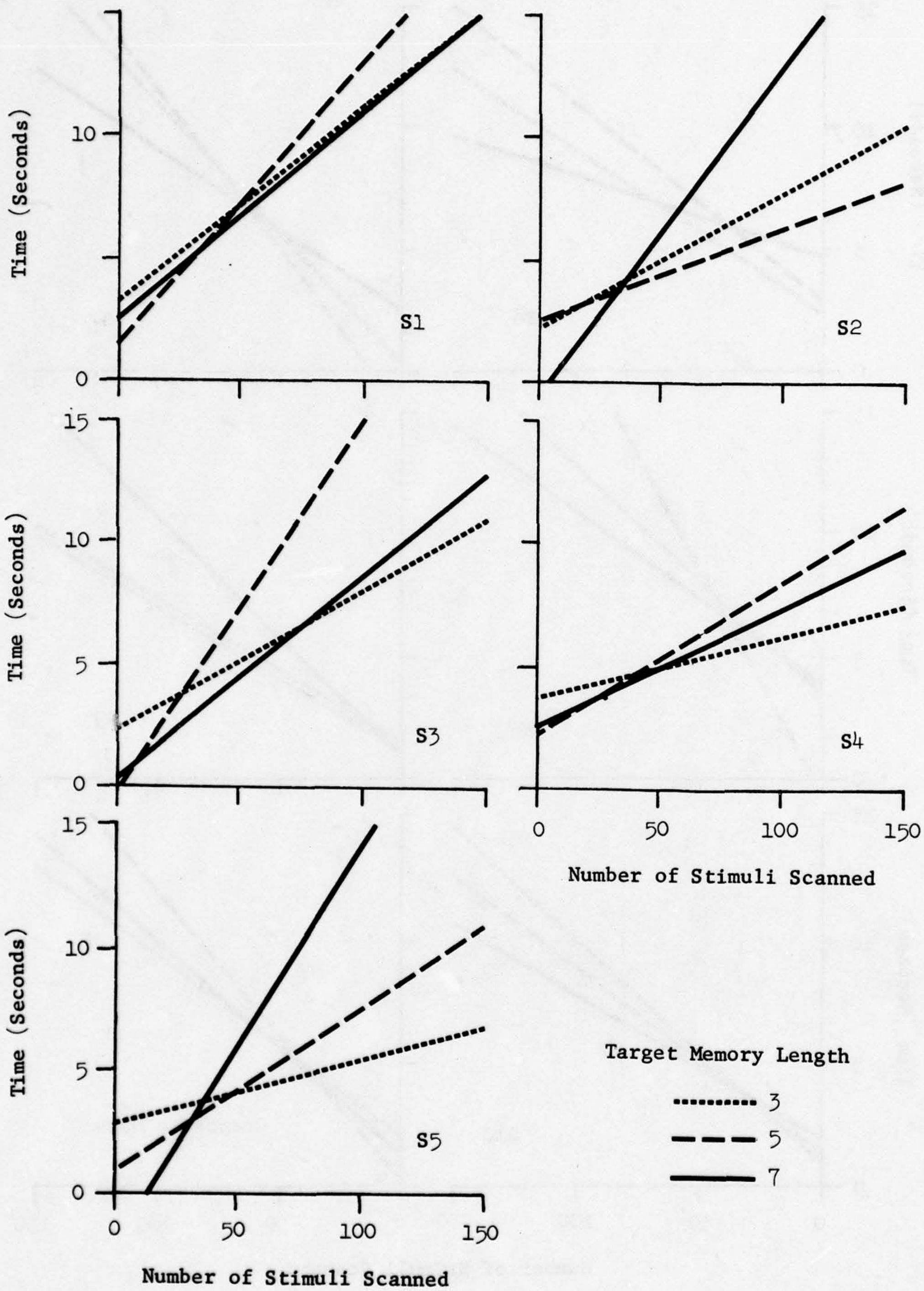
Table 10. Analysis of Variance Table for Scan Rates

Source	df	MS	F
Between Participants	9	.00112	
Within Participants	(20)		
Target Memory Length	2	.00110	1.29
Residual[a]	18	.00085	
Total[b]	(29)		

[a] Interaction term used as error term

[b] Between and Within

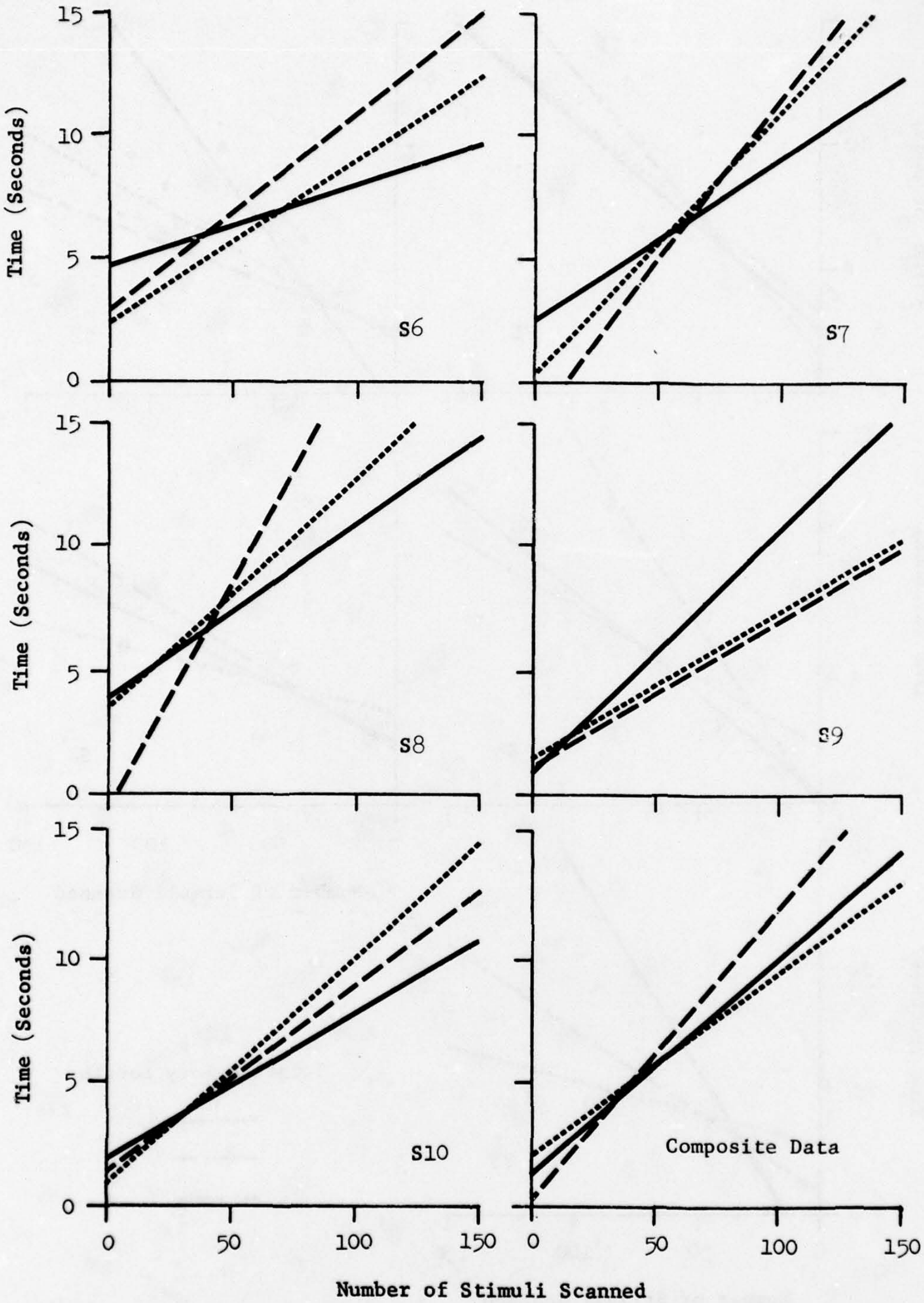
Note: Analysis of Variance is depicted for the scan rates of each participant within target memory conditions 3, 5, and 7.



(Page 1 of 2)

Scan rate slopes are shown for each participant in target memory length conditions 3, 5, and 7.

Figure 10. Scan Rate Slopes



(Page 2 of 2)

Also included are the median value slopes across participants for the three target memory length conditions.

Figure 10. Scan Rate Slopes

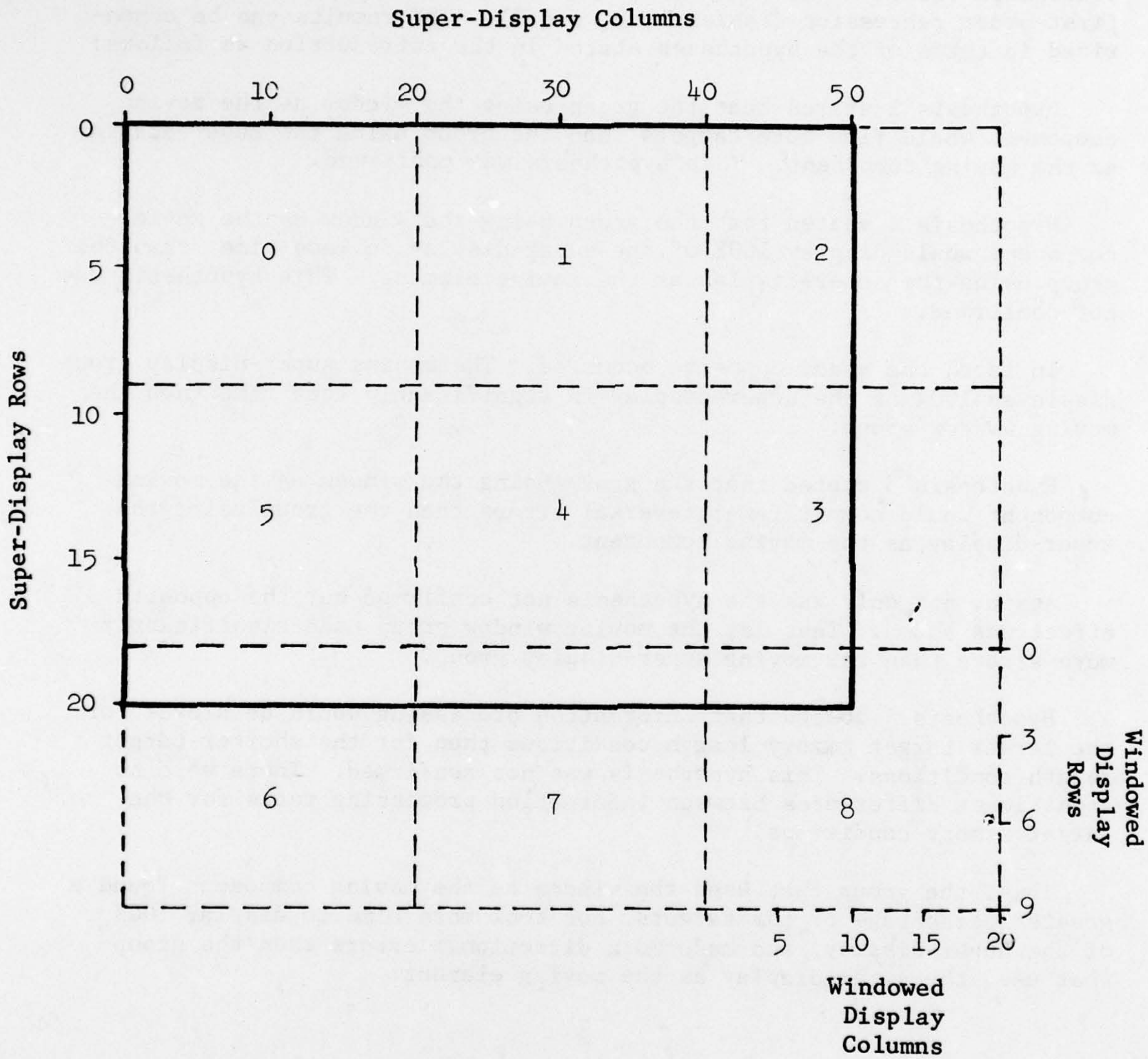


Figure 11. Typical Search Pattern

Participants employ a pattern whereby the solid rectangle represents the super-display. The dashed lines represent the windowed displays. The numerals represent the succession of "jumps," with zero representing the position of the display at the beginning of each trial.

Summary of the Major Experimental Results

Each of the three primary dependent measures, percent of targets detected, time to display 100% of the super-display, and number of directional command errors at the super-display boundary, was adequately described by a second-order regression equation (Tables 5, 7, and 9). In each case the proportion of variance explained by the second-order regression equation was relatively high and considerably better than a first-order regression (Tables 4, 6, and 8). The results can be summarized in terms of the hypotheses stated in the introduction as follows:

Hypothesis 1 stated that the group using the window as the moving component would find more targets than the group using the super-display as the moving component. This hypothesis was confirmed.

Hypothesis 2 stated that the group using the window as the moving component would display 100% of the super-display in less time than the group using the super-display as the moving element. This hypothesis was not confirmed.

In fact, the exact opposite occurred. The moving super-display group displayed 100% of the super-display in significantly less time than the moving window group.

Hypothesis 3 stated that the group using the window as the moving component would commit fewer reversal errors than the group using the super-display as the moving component.

Again, not only was the hypothesis not confirmed but the opposite effect was shown. That is, the moving window group made significantly more errors than the moving super-display group.

Hypothesis 4 stated that information processing would be slower for the larger target memory length conditions than for the shorter target length conditions. This hypothesis was not confirmed. There were no significant differences between information processing rates for the target memory conditions.

Thus, the group that used the window as the moving component found a greater percentage of the targets, but took more time to display 100% of the super-display, and made more directional errors than the group that used the super-display as the moving element.

CHAPTER 4

GENERAL DISCUSSION

The window technique appears to yield satisfactory performance in searching a large area on a small screen. However, display motion results based on aircraft display studies clearly cannot be extrapolated to those involving a user-viewer who can directly control the windowed display presented on a CRT.

The perceptual factors that people bring into a general display situation may be very much the same. Nevertheless, chances for perceptual confusion and disorientation may differ vastly from one specific display situation to another.

For instance, moving the window was assumed more natural than moving the super-display. It seemed that the larger component, the super-display, would be thought of best as the ground, and that the smaller component, the window, would be thought of as the figure. However, this view was much too simplistic. Results, although mixed, favor the super-display as the moving component.

In this study, the display motion relationship was more subtle than in the aircraft display studies. In the aircraft situation, regardless of which display the pilot used, the airplane was always moving.

In the present study this type of motion was not present. Prior to entry into the experimental booth the participant experienced himself as the moving object and the world around him as stationary. This would be the same experience that pilots have prior to getting into the cockpit.

When a participant in this study sat down to view the display, he became the stationary object and the CRT display passed before him.

In other words, the participant himself, the CRT frame, and all that the participant saw in peripheral vision remained stationary and became the frame of reference or the background. The only motion in this situation was the display which moved in front of the participant.

In conjunction with this frame of reference, participants in the moving window group might have visualized the situation as one in which they were operating a television camera and the display they saw on the CRT was a result of a "camera movement" which they themselves made.

Chapanis (1972 op cit) cautions against use of such intervening mechanisms to control movement display directions. However, in this study such an intervening mechanism could have led to disorientation.

The above interpretation implies that the moving super-display group should find a greater percentage of the targets. But this was not the case. The moving window group found a greater percentage of targets than the moving super-display group.

The moving window group possibly experienced more difficulty with display movement. Thus, the group spent more time seeing the entire display, made a greater number of directional command errors, and spent more time looking at sections already seen. This would then yield a greater probability that a target would be detected.

The present task environment may not be representative of the real world. Therefore, a number of empirical questions arise. For instance the participant was isolated from other people and extraneous visual activity. The only obvious visual motion that occurred took place on the CRT.

Suppose the participant was in an environment in which other people moved about while he was trying to perform his visual search task. Would the fact that the participant could see others move in his peripheral vision affect the display-control relationship?

Perhaps the assignment of additional task(s) requiring participants to move about the experimental area would have been more realistic. Would the user-viewer moving about affect the display motion relationship?

Performance utilizing the window technique also could be affected by whether the display is dynamic or static. The value of a computer-linked CRT increases immensely when the data being displayed change rapidly. This situation would make hard copy displays ineffective. The question remains on how people perform with a dynamic display which cannot be viewed in its entirety.

The task type factor is also very important. Using the window technique for viewing sections of a super-display that can be treated as separate displays, as in searching, is one situation.

What about the case in which information must be culled and integrated from different and relatively distant sections of the super-display? Is the window technique applicable to this type of task?

Within the context of a static visual search task the window technique has been shown to be a feasible and satisfactory approach. In general, many of the targets were found with relatively few errors.

In regard to the performance criteria and search parameters, this study provided the opportunity to make tentative recommendations for window display tasks.

In terms of non-target density, the present study confirms the earlier results of Baker, et al. (1960 op cit) that detection performance could be improved by essentially masking out as much irrelevant stimuli as possible. This conclusion, of course, assumes that a computer algorithm can be implemented which extracts only unneeded information.

Target density also affected time to display 100% of the super-display (Table 7) and number of directional command errors at the super-display boundary (Table 9). The more targets there were, the more time was used, and the more errors were made.

These results are attributed to the fact that the participants stopped searching the display in order to report and enter target location via the keyboard.

In situations in which increased search time and/or increased directional command errors are critical, changing the method of reporting a target may be advisable. For instance, if the requirement is merely to indicate the location of a target, a light-pen or a touch panel device may substantially improve performance.

If, on the other hand, an analysis of a target is required, e.g., to find the type of target or the strategic implications of the target location, it may be beneficial to have one man report the target and its location, and another man to perform the target analysis.

As predicted, window size was inversely related to the time to display 100% of super-display. This effect was attributed to the additional motor activity needed to display the entire super-display.

Thus, if search time is critical and if the display is not cluttered, a larger window size should be employed. This suggestion is somewhat tentative, however, in view of the fact that the super-display itself was not very large, i.e., 20 rows by 50 columns.

Performance was found constant over time (Tables 5, 7, and 9). However trial blocks and target density were involved in an interaction effect (Figure 9) as marked by the percent of targets detected.

It seemed as if the more targets in the later trials, the probability was less that they would all be detected. To counteract this possible effect, displays known or suspected to have a greater number of targets should be presented and searched earlier in the search time period.

Results concerning scan rate tend to favor a parallel processing model rather than a serial processing model. The scan rate was not significant for target memory lengths. Participants scanned the display stimuli as quickly for seven targets as they did for five or three targets.

The composite data for all 10 participants in each target memory length condition indicates no significant differences between target memory conditions.

However, there was much variability between participants for the scan rates. For instance, the graph for participant five (Figure 10) shows an increased slope for longer target memory lengths. However, the exact opposite can be seen in the graph for participant 10, i.e., decreased slope for longer target memory lengths.

Scan rate results agree with the Egeth, Marcus and Bevan's (1972 op cit) study. In the Egeth, et al study, as in the present investigation, participants worked with familiar target sets. Neither study produced evidence for serial processing in the early stages of information processing.

Parallel processing is possibly a primary function of how well the target set is learned. Learning may take place during the course of an experiment, (e.g., Neisser, et al., 1973 op cit) or in the course of everyday experience.

Thus, when a well-learned set of items, e.g., consecutive numbers is used as the target set, there is no need to practice. Performance equivalent to parallel processing can be observed readily.

These results have implications for both serial and parallel models. The models can be thought of, not as independent, but as evolutionary stages in learning to process information efficiently.

The serial model describes the result of information processing of unfamiliar target sets during early practice. The parallel model describes the result of information processing with an unfamiliar set after much practice has occurred, i.e., the target set has been well-learned, or in early practice using familiar target sets.

The evolving concept of information processing is similar to the chunking process of memory storage capacity (Miller, 1956*). This process essentially recodes information into fewer parts or chunks with more information contained in each chunk.

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*Miller, G. A. The Magical Number Seven, Plus or Minus Two: Some Limits on Our Capacity For Processing Information. Psychological Review, 1956, 63, 81-97.

For example, a two-stage chunking process might be the recoding of the binary digits 001110000111. Conversion of the binary digits to octal yields 1607; these four octal digits can be converted to the year of the settlement of Jamestown, the first permanent English settlement in North America.

In terms of the information processing well-learned target stimuli may be recoded or reorganized in memory somehow so that a more efficient process of searching, i.e., parallel processing, is developed.

The fact that target search time is not affected adversely by the length of the target list as long as that list is very well-learned has an important implication for visual search tasks.

Information processing can be improved by clearly defining each item in the target set, and by constructing the target list so that it conforms to a chain of well-associated stimuli.

CHAPTER 5

SUMMARY AND CONCLUSIONS

This study investigated two aspects of a search task in which the entire search field, i.e., super-display, cannot be displayed at one time. One aspect concerned the use of the window technique; the other concerned processing the stimulus information in regard to length of the memorized target list.

The principle of the moving part was investigated in relation to use of a window technique to determine which element of the display should be controlled, the window or the super-display.

In general, results show that in the context of a search task, a window technique is feasible and yields satisfactory performance; however, the results were mixed.

A higher percentage of targets was found by participants using a moving window. But participants in the moving super-display group made fewer control errors and took less time to view the entire super-display.

This result suggests that the display motion situation in this task is a complex one, and not sufficiently analogous to aviation displays to justify direct extrapolation from aviation research data.

Future research should consider more closely simulating a real world physical environment in which motion is not confined to the CRT display. Evidence for a parallel model of information processing was obtained in early search trials with the use of a well-defined target memory set.

Participants scanned the display stimuli as quickly for seven targets as for five or three targets. An information processing concept was discussed which evolves into a parallel mode from a serial mode as a function of the familiarity at the target set.

APPENDIX A

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